GeoSAR Airborne RADAR Results for the Alaska Statewide DEM Project

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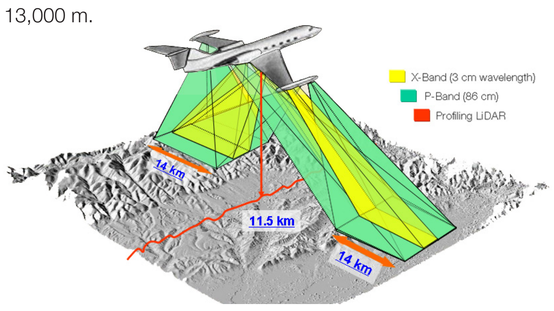
Abstract

Fugro's airborne, single-pass, dual-band Interferometric Synthetic Aperture Radar (IFSAR) system, GeoSAR, is presented in relation to the Alaska Statewide Digital Mapping Initiative (SDMI). Under this USGS contract, GeoSAR acquired data over an area of Alaska in July 2010. Deliverable products are the Digital Terrain Model (DTM), Digital Surface Model (DSM) and Orthorectified Radar Imagery (ORI). The main product is the DTM with 20-foot equivalent contour accuracy, corresponding to RMSEz=1.85m and RMSEr=8.03m (5.6 m in Northing and Easting) for the vertical and horizontal accuracy, respectively. The data are delivered in Alaska Albers projection with 5m post spacing, and in HRTe3 format in geographic projection. The elevation values are orthometric height, using the NGS Geoid09 model, and hydrologically enforced (rivers monotonically flowing down and lakes flattened, size >50x150m^2). These products will become public domain, when published by the USGS in the National Elevation Dataset (NED).

Airborne IFSAR was selected as the most appropriate technology to provide cost-efficient, high quality data products to fulfill the requirements of Alaska's state and federal stakeholders. GeoSAR incorporates a nadir-looking profiling LiDAR, from which 48,433 points in the Pilot Area are analyzed. Using these LiDAR measurements, the RMSEz of the DTM is estimated to be 1.11 m for terrain slopes between 0°–10°, and 1.54 m overall, including 2,035 points on slopes >30°.

The GeoSAR System

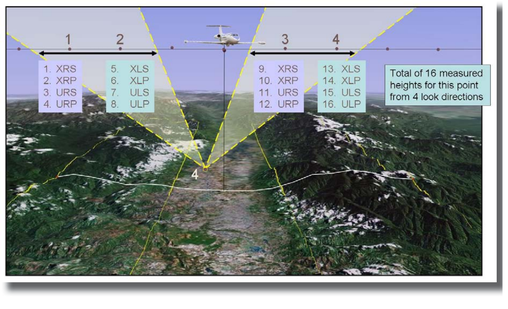
GeoSAR is a unique, state-of-the-art, dual-band, dual-sided, single-pass interferometric mapping radar, designed to efficiently map wide-area, both top vegetation canopies and the terrain beneath the canopy. The GeoSAR system was developed as a joint effort of NASA JPL and Fugro EarthData under sponsorship of DARPA and NGA. Flown on a Gulfstream-II jet aircraft, GeoSAR maps swaths simultaneously on both sides of the aircraft to generate high quality DEMs and imagery at both X-band and P-band. The system was augmented with a modified Leica ALS40 nadir-pointing LiDAR profiler system to measure highly accurate ground control points that are used during production of large area mosaics and as validation control with a vertical accuracy of better than 30 cm from altitudes up to 13,000 m.



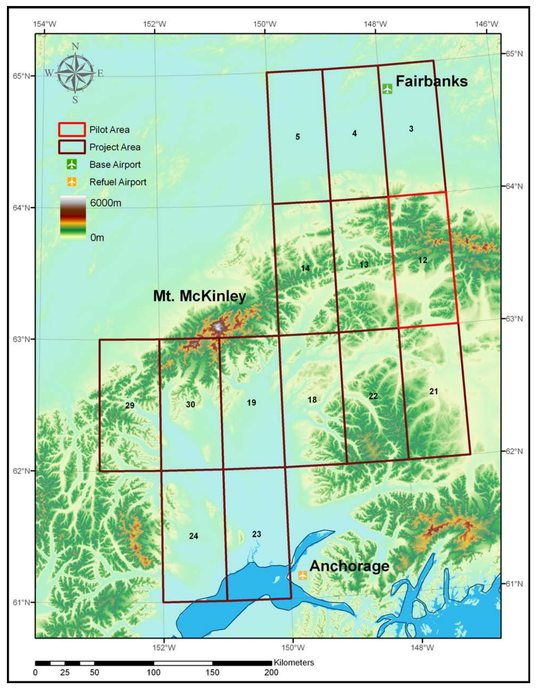
The GeoSAR radar flies aboard a Gulfstream-II modified jet at high altitude and high-speed. This configuration (above) makes it efficient for wide-area mapping applications, acquiring data on both sides of the plane simultaneously in X-band and P-band at a rate of approximately 300 km^2 per minute, per band (~400 MB per second).

Property	Advantage
Fugro	Expertise and stability of project management and quality processes. Full data ownership
Gulfstream-II platform	High-altitude, efficient wide area mapping suitable for flat terrain and extreme terrain
Single-Pass	No atmospheric errors or temporal decorrelation, operating in all-weather, day and night
Dual-Band (X+P)	Simultaneous mapping above and below the foliage for elevation and feature extraction (mapping)
Dual-Baseline (SAT+PP)	Reliability enhanced by additional height estimations and flexibility to use the proper processing mode for the product
Dual-Side (L+R)	Efficient and reliable mapping to get fast coverage and reduced shadow and layover, particularly in rough terrain
Quad-Pol (HH, HV, VH, VV)	Added value of interferometric polarimetry for a wide range of uses
Profiling LiDAR	Simultaneous reliable high-accurate ground control measurements provide on-board vertical control

A point on the ground is typically observed from four different directions (either from the Left or Right), each in four different interferometric modes (X-band and P-band, in Single-Antenna-Transmit and Ping-Pong mode), leading to 16 possible elevation estimations per pixel. The sketched nadir-looking profiling LiDAR provides independent ground control of the terrain directly below the flight path.



The Alaska Project

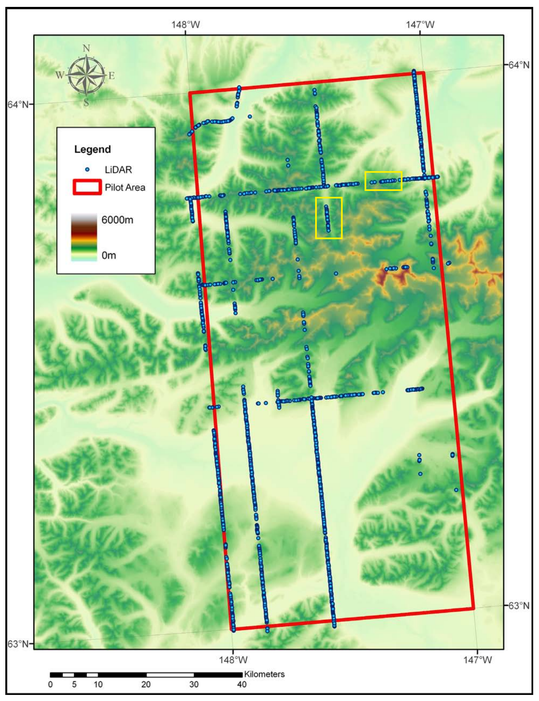


The project area (above), covering Fairbanks, Anchorage, and Mt. McKinley (Denali) towering 6,194m above sea level. The numbers refer to the priority of 1 degree cells given by the USGS. The images on the right show the highly varying terrain types and mixed land cover in the area, from flat and forested, to mountainous snow and ice covered terrain.

Product	Description	GeoSAR Observations
DTM	▪ Digital Terrain Model ▪ Geoid09 Orthometric Heights ▪ Vegetation and Buildings Removed ▪ Hydrologically Enforced	▪ P-band and X-band Interferometry ▪ Multiple Looks
DSM	▪ Digital Surface Model ▪ Geoid09 Orthometric Heights ▪ Hydrologically Enforced	▪ Based on X-band Interferometry ▪ Multiple Looks
ORI	▪ Orthorectified Radar Magnitude Image ▪ Multiple view directions average	▪ X-band ▪ Multiple Looks
Masks	▪ Quality Masks ▪ Hydrology, Voids, Fills, Slope category	▪ P-band and X-band
Meta	▪ Meta Information	▪ FDGC compliant

Table 1: Main Project Deliverables. Data are posted at 5 m, Alaska Albers projection.

Quality Assessment



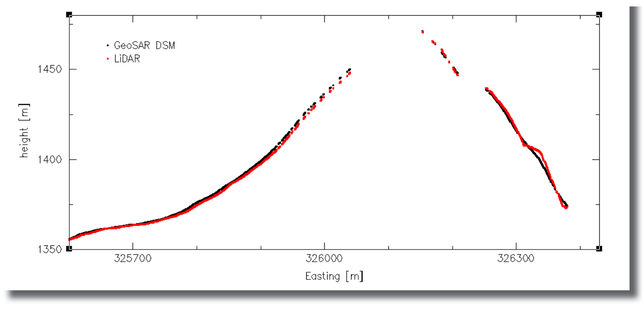
LiDAR points used for product quality assessment. The GeoSAR profiling LiDAR is a powerful tool to assess the horizontal and vertical accuracy of the delivered products. The LiDAR is designed to have a repeat precision of better than 30 cm vertical (one sigma). The LiDAR footprint is 3-5 m, depending on height above the terrain, and the sample density is approximately 3 cm, with 3-returns and 3 intensities. The horizontal accuracy (RMSE) of the LiDAR is about half the footprint.

Slope	0°- 10°	10°- 20°	20°- 30°	30°+	Overall
Number of Points	32184	10358	3856	2035	48433
Average (m)	-0.12	0.63	0.98	1.16	0.18
Standard Deviation (m)	1.10	1.55	1.71	3.04	1.45
Minimum Difference (m)	-8.04	-17.90	-8.04	-8.04	-52.88
Maximum Difference (m)	16.35	11.48	15.96	25.07	25.07
RMSE (m)	1.13	1.64	1.97	3.25	1.46

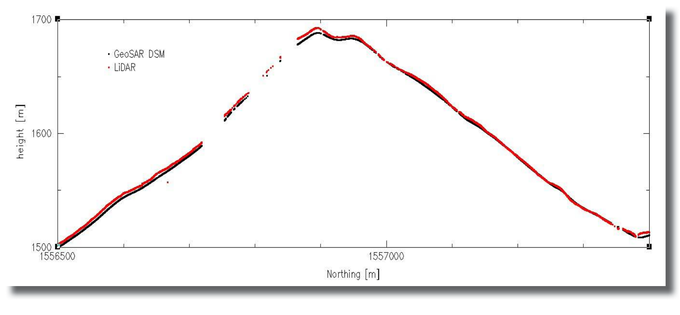
Table 2: Vertical accuracy assessment of the DSM product for the Pilot Area based on LiDAR data. (not culled).

A total of 12,628,042 usable LiDAR points are available in the Pilot Area, as shown in the above Figure. These points are remaining after eliminating all LiDAR points with an elevation higher than the maximum elevation in the Pilot Area, i.e., the data are cleaned from cloud returns. As the LiDAR data are acquired directly below the aircraft, the pattern of North-South mapping lines and orthogonal cross-ties is visible. Locations that do not show LiDAR points were flown in cloudy conditions, as the GeoSAR radar is not affected by clouds, and data acquisition continues under such circumstances.

For this analysis, the available 12,628,042 LiDAR points are sub-sampled by a factor 200 to reduce the amount of points and create a sampling density of approximately 5 m; the same as the DEM products. Secondly, LiDAR returns from water bodies are removed using the water mask created for this project as a deliverable, leaving a total of 48,433 LiDAR points. These points are used to validate the accuracy of the DSM and DTM product, without further culling, see Table 2.



LiDAR profile for an East-West line over mountainous terrain with terrain slopes of ~10°–25°. The difference between the LiDAR and the DSM is approximately 1.5 m. It can be clearly seen that the DSM aligns well with the LiDAR profile data, and that mountain ridges are correctly located in the IFSAR data.



North-South LiDAR profile over mountainous terrain with terrain slopes of ~25°. The difference between the LiDAR and the DSM is ~2.5 m on the slope and ~3.5 m at the peak. It can be clearly seen that the DSM aligns well with the LiDAR profile data, and that mountain ridges are correctly located in the IFSAR data.